Biomechanical Evaluation of Mini-Open and Percutaneous Achilles Repair Techniques During Simulated Early Progressive Rehabilitation

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Introduction: The Achilles tendon is the largest tendon in the body and is capable of withstanding forces in excess of 9,000 N and 12.5 times body weight [3]. Despite its substantial strength, rupture of the Achilles tendon is relatively common, ranking third in frequency among major tendon ruptures [2,4]. In the case of tendon rupture, many options exist ranging from non-operative treatment to open surgical repair. While non-operative management is a viable option, surgical repair remains a common treatment in many individuals including young and athletic populations [2]. More recently, minimally invasive percutaneous surgical repair methods have been developed. Open and percutaneous techniques have been reported to result in similarly satisfactory clinical outcomes; however, neither technique is without limitations. Open repairs are accompanied by potential wound healing complications while percutaneous techniques have been reported to carry an increased risk of iatrogenic sural nerve injury in addition to debates regarding fixation strength at time zero. The purpose of the present study was to biomechanically analyze three commercially available percutaneous techniques and a mini-open Achilles repair during a simulated progressive rehabilitation program.

Methods: Thirty-three fresh frozen, foot and ankle cadaveric specimens with no previous history of Achilles injury, surgery, or other confounding pathology were included in the final analysis. Sample sizes (n = 9, except Achillon where n = 6) were determined a priori to detect an effect size of one with 80% power when comparing repair construct elongation. Specimens were randomly assigned to one of four different Achilles repair techniques (Figure 1): (1) Mini-open repair, (2) Achillon® Achilles Tendon Suture System (Integra LifeSciences Corporation, Plainsboro NJ), (3) PARS Achilles Jig System (Arthrex Inc., Naples FL), or (4) Achilles SpeedBridgeTM (Arthrex Inc., Naples FL).
A simulated mid-substance Achilles rupture was created 6 cm proximal to the calcaneal insertion through a 2 cm standardized horizontal incision and subsequently repaired with one of the four randomly assigned techniques. Mini-open repairs consisted of three modified Kessler suture repairs using three #2 braided polyethylene/polyester multifilament sutures followed by a running suture using 3-0 monocryl suture spanning the width of the tendon. Percutaneous repairs were performed in accordance with their corresponding technique guide. Surgical repairs were isolated and calcanei were potted in polymethyl-methacrylate. The potted calcanei were secured in an adjustable fixture and rigidly clamped to the base of a dynamic tensile testing machine (ElectroPuls E10000, Instron Systems, Norwood, MA). Repairs were subjected to a cyclic loading protocol representative of progressive postoperative rehabilitation: 250 cycles at 1 Hz for each of the following load ranges: (1) 20-100 N, (2) 20-200 N, (3) 20-300 N, (4) 20-400 N. Loads were selected based on previous literature describing load ranges experience by the Achilles tendon during passive ankle flexion and walking in a Cam Walker with and without a one inch heel lift [1,5]. Load and displacement were monitored continuously throughout testing. Statistical analysis was performed to compare differences between treatment groups. Differences were deemed significant for p-values < 0.05.

Results: During biomechanical testing, all repairs survived the first 250 cycles of cyclic loading from 20-100 N while no repairs survived all four loading stages (1000 cycles). However, within the first loading stage, significant differences were observed in the elongation (displacement) of repairs (Figure 2).
Following the first 250 cycles of cyclic loading, the mini-open (OPEN) repair technique had an average (± SD) elongation of 5.2 ± 1.1 mm which was significantly lower than all percutaneous repair methods. There were no significant differences observed between the elongation of repairs using the Achillon (ACH), PARS Achilles Jig System (PARS), or SpeedBridge (SB) with displacements of 9.9 ± 2.2 mm, 12.2 ± 4.4 mm, and 10.0 ± 3.9 mm at the end of the first loading stage (250 cycles), respectively. When examined over smaller cyclic intervals, the majority of elongation, regardless of repair, occurred within the first 10 cycles. After 10 cycles, mini-open repairs had already achieved 3.7 ± 0.8 mm (71.1%) of the elongation observed at the conclusion of the first 250 cycles. Similarly, the Achillon, PARS Achilles Jig System, and SpeedBridge each achieved 8.1 ± 2.3 mm (81.8%), 9.5 ± 4.3 mm (77.8 %), and 6.9 ± 2.4 mm (69.0%) of the elongation following 250 cycles, respectively. Despite differences in displacement between percutaneous techniques and the mini-open repair, no significant differences were observed in the total number of cycles to failure during progressive cyclic loading. All repairs failed by suture cut-out at the suture-tendon interface. However, it should be noted that repairs failing within the first 10 cycles or those in which the proximal or distal tendon remnant was not sufficiently captured during percutaneous repair, as indicated by visual inspection during dissection and specimen preparation for testing, were deemed to be “failed repairs” and excluded from final analysis. Six tendons repaired with the Achillon device failed to capture the tendon, missing anteriorly, while one PARS Jig System Repair missed the tendon anteriorly. One SpeedBridge repair was excluded due to insufficient suture-anchor purchase in the calcaneus. No mini-open repairs were deemed “failed repairs”. Due to the number of failed Achillon repairs and specimen availability, the desired sample size of nine could not be achieved.
**Discussion:** Differences in early repair elongation during simulated progressive rehabilitation suggest that surgical repair technique should be considered when prescribing postoperative rehabilitation. Reduced early elongation of mini-open repairs suggests that patients treated with this technique may be able to progress through an earlier and/or more aggressive postoperative protocol without the risk of early irrevocable repair elongation or gapping about the repair site. However, in cases where cosmesis or wound healing complications are of significant concern, percutaneous techniques provide a biomechanically reasonable alternative given the presented repair strengths (cycles to failure). Nevertheless, based on the findings of this study, percutaneous repairs should be protected longer postoperatively to allow for biologic healing and avoid early repair elongation and potential gapping between the healing tendon ends.

**Significance:** In conclusion, when surgery is chosen as the treatment method for a mid-substance Achilles tendon rupture, both mini-open and percutaneous techniques appear to be viable options for repairs. Indications for selection of mid-substance Achilles repair and a specific repair technique should be made on an individual basis considering a patient’s physical demands, healing capacity, cosmetic concerns, and rehabilitation requirements in addition to surgeon experience and comfort level with the percutaneous methods. The present study offers data describing the early biomechanical behavior of repair constructs which may help guide treatment based on these individual patient considerations.

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